

# Bottom partner $B'$ and $Zb$ production at the $LHC$

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## Abstract

Some new physics models, such as "beautiful mirrors" scenario, predict the existence of the bottom partner  $B'$ . Considering the constraints from the data for the  $Z \rightarrow b\bar{b}$  branching ratio  $R_b$  and the  $FB$  asymmetry  $A_{FB}^b$  on the relevant free parameters, we calculate the contributions of  $B'$  to the cross section  $\sigma(Zb)$  and the  $Z$  polarization asymmetry  $A_Z$  for  $Zb$  production at the  $LHC$ . We find that the bottom partner  $B'$  can generate significant corrections to  $\sigma(Zb)$  and  $A_Z$ , which might be detected in near future.

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## 1. Introduction

Over the past several decades, the standard model ( $SM$ ) has provided a consistent description of particles physics and is tested to per-mille precision by experimented data. Recently, the *ATLAS* and *CMS* collaborations have independently reported the discovery [1] of a neutral scalar particle that seems consistent with the  $SM$  Higgs boson with a mass of about  $125 \sim 126 GeV$ . However, some observables related to the sector of third generation quarks have been observed large deviations from their  $SM$  predictions. The first is the forward-backward ( $FB$ ) asymmetry of the bottom-quarks,  $A_{FB}^b$ , which differs by about  $2.5\sigma$  deviation from the  $SM$  value at the  $Z$  boson pole according the recent global fit result [2]. The second is the  $FB$  asymmetry  $A_{FB}^t$  in top quark pairs produced at the Tevatron, which has larger value than the  $SM$  prediction [3]. Furthermore, a recent calculation of the  $Z \rightarrow b\bar{b}$  branching ratio  $R_b$ , which includes new two-loop electroweak corrections, now puts the prediction in tension with the measured value [4].

It is well known that the top loop in the  $SM$  is the largest contribution to the Higgs mass quadratic divergence. Thus, for the new physics models to solve the fine tuning problem, there must be some new particles constrained by symmetry, which cancel this loop. Most of these new physics models should contain a heavy particle which shares the gauge quantum numbers of the top quark, generally called "top partner" [5]. This new particle should be in an electroweak doublet in order to properly cancel the divergences to the Higgs mass produced by the top loop. So, this kind of new physics models beyond the  $SM$  predicts the existence of the heavy partner  $B'$  of the bottom quark. Furthermore, if the top and bottom partners have the same mass hierarchy as the  $SM$  top and bottom, the new quark  $B'$  may be the first to be discovered, which has began to be searched at the Tevatron and LHC [6].

Production of the electroweak gauge boson  $Z$  associated with a bottom quark at the *LHC* is an important background process not only to Higgs boson production and single top production, but also to the search for signals of new physics beyond the  $SM$ , which has been calculated at next-to-leading order ( $NLO$ ) [7]. Recently, Ref.[8] has defined the

$Z$  polarization asymmetry  $A_Z$  in the subprocess  $gb \rightarrow Zb$  at the  $LHC$  and has shown that  $A_Z$  is strictly connected to the  $FB$  asymmetry  $A_{FB}^b$  and is almost free from the theoretical uncertainties related to  $QCD$  scale and parton distribution function ( $PDF$ ) set variations.

Considering the constraints of the data from  $LEP$  for the  $Z \rightarrow b\bar{b}$  branching ratio  $R_b$  and the  $FB$  asymmetry  $A_{FB}^b$  [9] on the  $Zb\bar{b}$  couplings  $g_L^b$  and  $g_R^b$ , we are model-independent of calculating the contributions of the new physics beyond the  $SM$  to  $Zb$  production at the  $LHC$  in section 2. We find that the correction terms  $\delta g_L^b$  and  $\delta g_R^b$  generated by new physics cannot give significant contributions to the production cross section  $\sigma(Zb)$ . While it is not this case for the  $Z$  polarization asymmetry  $A_Z$ . In section 3, we study the correction effects of the bottom partner  $B'$  on the production cross section  $\sigma(Zb)$  and the  $Z$  polarization asymmetry  $A_Z$ . Our numerical results show that, with reasonable values of the relevant free parameters,  $B'$  can generate large corrections to  $\sigma(Zb)$  and  $A_Z$ . Our conclusion is given in section 4.

## 2. The new physics and $Zb$ production at the $LHC$

For the 5-flavor scheme [10], production of the electroweak gauge boson  $Z$  associated with a bottom quark at the  $LHC$  proceed via two Feynman diagrams with  $b$ -quark exchange in the  $s$ -channel and the  $t$ -channel at leading order. Its production cross section  $\sigma(Zb)$  is proportional to the factor  $[(g_L^b)^2 + (g_R^b)^2]$ . Thus, new physics can produce contributions to  $\sigma(Zb)$  via correcting the  $Zb\bar{b}$  couplings  $g_L^b$  and  $g_R^b$ .

The effective  $Zb\bar{b}$  couplings can be parameterized by the Lagrangian

$$\mathcal{L} = \frac{e}{S_W C_W} \bar{b} \gamma^\mu [(g_L^{b,SM} + \delta g_L^b) P_L + (g_R^{b,SM} + \delta g_R^b) P_R] b Z_\mu, \quad (1)$$

with  $S_W = \sin\theta_W$  and  $C_W = \cos\theta_W$ , in which  $\theta_W$  is the electroweak mixing angle.  $P_{L/R} = (1 \mp \gamma_5)/2$  are the chirality projection operators. The  $SM$  tree-level couplings  $g_L^{b,SM}$  and  $g_R^{b,SM}$  can be written as  $:-\frac{1}{2} + \frac{1}{3}S_W^2$  and  $\frac{1}{3}S_W^2$ , respectively.  $\delta g_L^b$  and  $\delta g_R^b$  represent the new physics contributions to the  $Zb\bar{b}$  couplings. In principle, the corrections of new physics to the  $Zb\bar{b}$  vertex may give rise to one magnetic moment-type form factor,

proportional to  $\sigma^{\mu\nu}q_\nu$ . However, its contributions to the  $Z \rightarrow b\bar{b}$  branching ratio  $R_b$  and the  $FB$  asymmetry  $A_{FB}^b$  are very small and thus have been neglected in above equation.

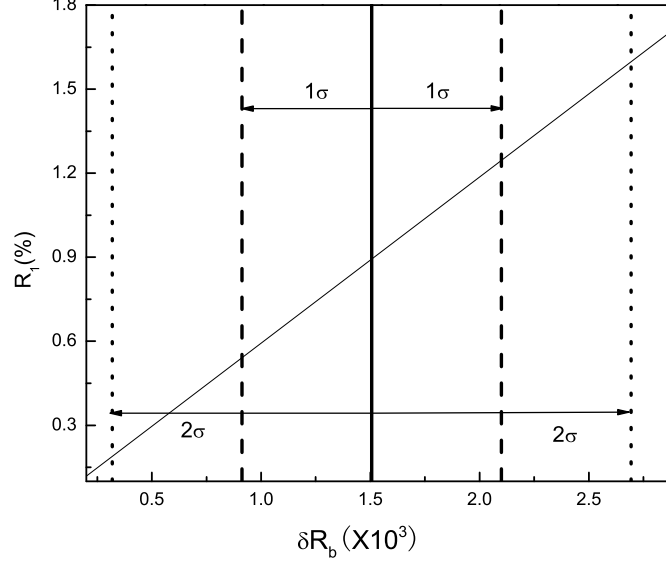


Figure 1: The relative correction parameter  $R_1$  is presented as a function of  $\delta R_b$ . The regions between dashed lines and between dotted lines correspond  $1\sigma$  and  $2\sigma$  allowed regions from  $R_b$  constraints, respectively.

The relative corrections of new physics to  $R_b^{SM}$  and  $A_{FB}^{b,SM}$  can be approximately written as [11]

$$\frac{\delta R_b}{R_b^{SM}} \simeq 2(1 - R_b^{SM}) \frac{g_L^{b,SM} \delta g_L^b + g_R^{b,SM} \delta g_R^b}{(g_L^{b,SM})^2 + (g_R^{b,SM})^2}, \quad (2)$$

$$\frac{\delta A_{FB}^b}{A_{FB}^{b,SM}} \simeq \frac{4(g_L^{b,SM})^2 (g_R^{b,SM})^2}{(g_L^{b,SM})^4 - (g_R^{b,SM})^4} \left( \frac{\delta g_L^b}{g_L^{b,SM}} - \frac{\delta g_R^b}{g_R^{b,SM}} \right). \quad (3)$$

Where  $\delta R_b = R_b^{exp} - R_b^{SM}$  and  $\delta A_{FB}^b = A_{FB}^{b,exp} - A_{FB}^{b,SM}$ . In above equations, we have neglected the new physics corrections to the  $Ze\bar{e}$  couplings  $g_L^e$  and  $g_R^e$ . The experimental results for  $R_b$  and  $A_{FB}^b$  are [9]

$$R_b^{exp} = 0.21629 \pm 0.00066, \quad A_{FB}^{b,exp} = 0.0992 \pm 0.0016. \quad (4)$$

The recent  $SM$  prediction for  $R_b$ , including electroweak two-loop and QCD three-loop corrections is  $R_b^{SM} = 0.21474 \pm 0.00003$ , which deviates by  $2.4\sigma$  deviations below the experimental measured value [2, 4], while the recent global fit result for  $A_{FB}^b$  is  $A_{FB}^{b,SM} = 0.1032_{-0.0006}^{+0.0004}$ , which is still above the experimental measured value by  $2.5\sigma$  deviations [2].

Using above experimental and  $SM$  prediction values, one can easily obtain the constraints of the electroweak precision data on the new  $Zb\bar{b}$  couplings  $\delta g_L^b$  and  $\delta g_R^b$ . It is obvious that the data favor small corrections to  $\delta g_L^b$  and more large shifts in  $\delta g_R^b$ . Considering the discovery of a Higgs-like particle at the  $LHC$ , Ref. [12] has updated the constraints of the electroweak precision data on  $\delta g_L^b$  and  $\delta g_R^b$  and there is

$$\delta g_L^b = 0.001 \pm 0.001, \quad \delta g_R^{b+} = 0.016 \pm 0.005, \quad \delta g_R^{b-} = -0.17 \pm 0.05. \quad (5)$$

We use the relative correction parameter  $R_1 = [\sigma(Zb) - \sigma^{SM}(Zb)]/\sigma^{SM}(Zb)$  to describe the corrections of the new  $Zb\bar{b}$  couplings  $\delta g_L^b$  and  $\delta g_R^b$  to the cross section of the process  $pp \rightarrow Zb$ , in which  $\sigma(Zb)$  denotes the total production cross section including the contributions from the  $SM$ ,  $\delta g_L^b$ , and  $\delta g_R^b$ . In our calculations, the  $PDFs$  of the bottom quark and gluon are taken as the  $CTEQ6L$   $PDFs$  [13] with renormalization and factorization scales  $\mu_R = \mu_F = M_Z$ . To make our numerical results more realistic, we have applied the cuts on the  $b - jet$  with transverse momentum  $P_T > 15 GeV$  and a rapidity range  $|\eta| < 2$ . It is obvious that the radiative corrections to  $\sigma(Zb)$  and  $\sigma^{SM}(Zb)$  are canceled in the relative correction parameter  $R_1$ . In Fig.1 we plot  $R_1$  as a function of  $\delta R_b$  for  $1\sigma$  and  $2\sigma$  constraints from the  $R_b$  experimental value. One can see that the value of  $R_1$  allowed by the  $R_b$  constraints is very small. For the theory value of  $R_b$  being consistent with its experimental value with  $1\sigma$  and  $2\sigma$  error bars, the values of the parameter  $R_1$  are in the ranges of  $0.53\% \sim 1.3\%$  and  $0.14\% \sim 1.7\%$ , respectively, which are much smaller than the  $QCD$  corrections [7].

Searching for the gauge boson  $Z$  produced in association with the bottom quark has been performed at the  $LHC$ . Recently, the  $ATLAS$  collaboration [14] has reported their measurement of the  $Zb$  production cross section and found that it is in good agreement with the  $SM$  prediction including the  $NLO$   $QCD$  corrections. Considering the statistical

and systematic uncertainties, the *ATLAS* data cannot give severe constraints on the new  $Zb\bar{b}$  couplings  $\delta g_L^b$  and  $\delta g_R^b$ .

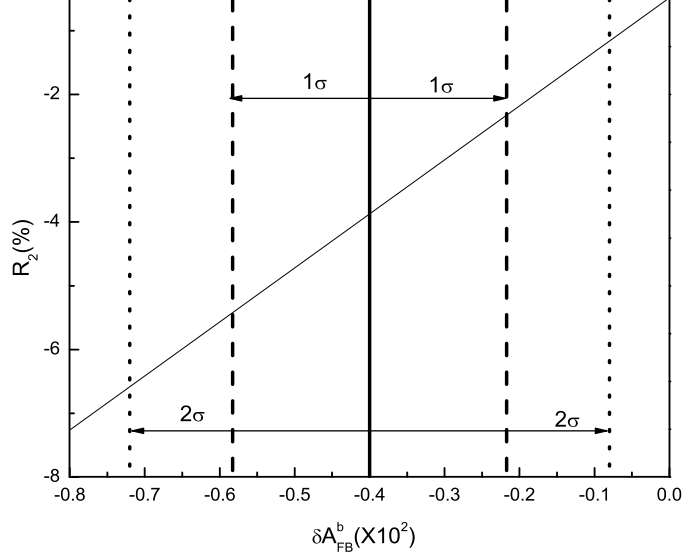


Figure 2: The relative correction parameter  $R_2$  as a function of  $\delta A_{FB}^b$ . The regions between dashed lines and between dotted lines correspond  $1\sigma$  and  $2\sigma$  allowed regions from  $A_{FB}^b$  constraints, respectively.

Compared to the cross section, decay width, etc, the asymmetry, which is defined as a ratio of observables, is not sensitive to the theoretical uncertainties. The asymmetry can be utilized to study the detail properties of the particles and further to investigate underlying dynamics in and/or beyond the *SM*. Measurement of the asymmetry at the *LEP* and Tevatron has provided rich informations about the *SM* and various new physics models.

The  $Z$  polarization asymmetry  $A_Z$  in  $Zb$  production at the *LHC* can be defined as

$$A_Z = \frac{\sigma(Z_R b) - \sigma(Z_L b)}{\sigma(Z_R b) + \sigma(Z_L b)}, \quad (6)$$

where  $\sigma(Z_R b)$  and  $\sigma(Z_L b)$  are the hadronic cross sections of  $Z_R b$  and  $Z_L b$  production at the LHC, respectively. Ref.[8] has shown that  $A_Z$  is connected to the  $Zb\bar{b}$  *FB* asymmetry

$A_{FB}^b$  and given its  $SM$  prediction value. If the large deviation between the  $SM$  prediction and the  $LEP$  measurement of  $A_{FB}^b$  indeed exists and comes from the new  $Zb\bar{b}$  couplings  $\delta g_L^b$  and  $\delta g_R^b$ , then these new couplings should generate significant contributions to  $A_Z$ .

To see whether the correction effects of the new  $Zb\bar{b}$  couplings  $\delta g_L^b$  and  $\delta g_R^b$  on the  $Z$  polarization asymmetry  $A_Z$  can be detected at the  $LHC$ , we define the relative correction parameter  $R_2 = \delta A_Z / A_Z^{SM}$  with  $\delta A_Z = A_Z^{total} - A_Z^{SM}$ . Our numerical results are shown in Fig.2, in which we plot  $R_2$  as a function  $\delta A_{FB}^b$  to consistent with the experimental value of  $A_{FB}^b$  with  $1\sigma$  and  $2\sigma$  error bars. One can see that the absolute value of  $R_2$  can reach 6.8%. Considering  $A_Z$  almost free from the theoretical uncertainties, we hope that the  $LHC$  might detect this correction effects and confirm or obviate the  $A_{FB}^b$  anomaly.

### 3. The bottom partner $B'$ and $Zb$ production at the $LHC$

So far, the  $Zb\bar{b}$   $FB$  asymmetry  $A_{FB}^b$  measured in  $Z$  boson decays at  $LEP$  experiments still exist  $2.5\sigma$  deviations from the  $SM$  prediction [2]. Considering modification of the  $SM$   $Zb\bar{b}$  couplings  $g_L^{b,SM}$  and  $g_R^{b,SM}$ , some new physics models have been proposed to cure the large discrepancy [15, 16, 17]. Ref. [17] proposed the beautiful mirrors model, which introduces vector-like quarks which mix with the bottom quark subtly affecting its couplings to the gauge boson  $Z$  and addressing the observed anomaly in  $A_{FB}^b$ . This model predicts the existence of the bottom partner  $B'$ . Some of their phenomenological consequences have been explored in Refs. [17, 18]. Taking into account of the constraints on the relevant free parameters from explaining the current  $R_b$  and  $A_{FB}^b$  deviations [2, 4, 12], we consider the contributions of the bottom partner  $B'$  to the hadronic cross section  $\sigma(Zb)$  and the  $Z$  polarization asymmetry  $A_Z$  for  $Zb$  production at the  $LHC$  in this section.

The beautiful mirrors model [17] extends the  $SM$  by introducing two sets of vector-like quarks,  $\psi_{L,R}$  with quantum numbers  $(3, 2, -5/6)$  and  $\xi_{L,R}$  with quantum numbers  $(3, 1, -1/3)$ , in which the  $SM$  Higgs is the only source of electroweak symmetry breaking

(*EW**SB*). In terms of its  $SU(2)$  components,  $\psi_{L,R}$  decomposes as

$$\psi_{L,R} = \begin{pmatrix} \omega_{L,R} \\ \chi_{L,R} \end{pmatrix}, \quad (7)$$

where  $\omega$  is a charge -1/3 quark and  $\chi$  has charge -4/3. It is assumed that the new quarks only couple to the third generation *SM* quarks, which are governed by the  $SU(3) \times SU(2) \times U(1)$  gauge invariance. These new quarks mix with the *SM* bottom quark to explain the measured value of  $A_{FB}^b$  and have small mixing with the two lighter *SM* generation quarks to satisfying the constraints from rare decay processes of the bottom and strange mesons such as  $B \rightarrow X_s \gamma$ ,  $B \rightarrow l^+ l^- X$ ,  $B \rightarrow J/\Psi K_s$  and  $K \rightarrow \pi \nu \bar{\nu}$ .

In the beautiful mirrors model, the couplings between the gauge boson  $Z$  and the down-type quarks may be written in matrix form [17]

$$\mathcal{L}_Z = \frac{e}{S_W C_W} \bar{d} \gamma^\mu (L P_L + R P_R) d Z_\mu + h.c., \quad (8)$$

where  $d = (b_1, b_2, b_3)$ , in which  $b_1$  is mainly the *SM* bottom quark field,  $b_2$  is mostly  $\omega$  and  $b_3$  is mostly  $\xi$ . We call  $b_2$  as bottom partner  $B'$  and consider its contributions to  $Zb$  production at the *LHC*. The coupling matrices  $L$  and  $R$  are written as

$$L = U_d^\dagger g_L U_d, \quad R = W_d^\dagger g_R W_d, \quad (9)$$

where  $g_L = \text{Diag}(-\frac{1}{2} + \frac{1}{3}S_W^2, \frac{1}{2} + \frac{1}{3}S_W^2, \frac{1}{3}S_W^2)$ ,  $g_R = \text{Diag}(\frac{1}{3}S_W^2, \frac{1}{2} + \frac{1}{3}S_W^2, \frac{1}{3}S_W^2)$ . The unitary matrices  $U_d$  and  $W_d$  transform the left- and right-handed gauge eigenstates into the corresponding mass eigenstates, which can diagonalize the mass matrix,

$$U_d^\dagger M_d W_d = \begin{pmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{pmatrix}, \quad (10)$$

where  $m_1 = m_b$ ,  $m_2$  and  $m_3$  are the *SM* bottom quark mass, and two new quark masses. The matrix  $U_d$  can be parameterized as

$$U_d = \begin{pmatrix} C_{12}^L C_{13}^L & S_{12}^L C_{13}^L & S_{13}^L \\ -S_{12}^L C_{23}^L - C_{12}^L S_{23}^L S_{13}^L & C_{12}^L C_{23}^L - S_{12}^L S_{23}^L S_{13}^L & S_{23}^L C_{13}^L \\ S_{12}^L S_{23}^L - C_{12}^L C_{23}^L S_{13}^L & -C_{12}^L S_{23}^L - S_{12}^L C_{23}^L S_{13}^L & C_{23}^L C_{13}^L \end{pmatrix}, \quad (11)$$



with  $C_{12}^L = \cos\theta_{12}^L$  and so on, in which  $\theta_{ij}$  are the mixing angles. The matrix  $W_d$  has an analogous expression but with  $\theta_{ij}^L \rightarrow \theta_{ij}^R$ .

Using above equations, one can write the explicit expression forms for the  $Zb\bar{b}$ ,  $ZB'\bar{B}'$ ,  $Zb\bar{B}'$  couplings, etc, and further give the correction terms  $\delta g_L^b$  and  $\delta g_R^b$  to the  $SM$   $Zb_L\bar{b}_L$  and  $Zb_R\bar{b}_R$  couplings. To predigest our calculation, we set  $S_{12}^R = S_R \neq 0$ ,  $S_{13}^L = S_L \neq 0$ , and all other mixing angles equal to zero. In this simply case, the couplings, which are related our calculation, can be written as

$$\delta g_L^b = \frac{S_L^2}{2}, \quad \delta g_R^b = \frac{S_R^2}{2}; \quad (12)$$

$$g_L^{bB'} = 0, \quad g_R^{bB'} = -\frac{e}{2S_W C_W} S_R C_R. \quad (13)$$

Comparing the experimental measured values of the  $Z \rightarrow b\bar{b}$  branching ratio  $R_b$  and  $FB$  asymmetry  $A_{FB}^b$  with their current theoretical prediction values [2, 4], one can obtain the constraints on the mixing parameters  $S_L$  and  $S_R$ . To make  $A_{FB}^b$  and  $R_b$  consistent with their experimental measured values with  $1\sigma$  and  $2\sigma$  error bars, the mixing parameters  $S_L$  and  $S_R$  must satisfy the relation

$$1\sigma : \quad 0 \leq S_L^2 \leq 0.004, \quad 0.022 \leq S_R^2 \leq 0.042; \quad (14)$$

$$2\sigma : \quad 0 \leq S_L^2 \leq 0.006, \quad 0.012 \leq S_R^2 \leq 0.052. \quad (15)$$

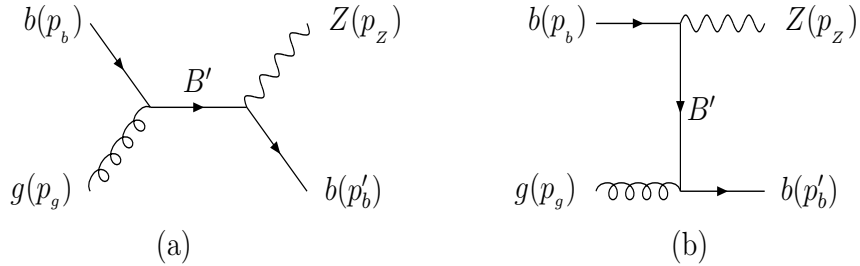


Figure 3: Feynman diagrams for the  $B'$  contributions to  $Zb$  production at the  $LHC$ .

The couplings of the  $SM$  quarks and new down-type quarks to the Higgs boson  $H$  and the gauge boson  $W$  can be obtained from Ref. [17].

The couplings of the new fermions to the  $SM$  gauge bosons and ordinary fermions are uniquely fixed by gauge invariance [19]. The general Lagrangian describing the interactions between the  $SM$  bottom quark, its partner  $B'$  and gluon is fixed by  $SU(3)$  gauge invariance to be of magnetic moment type [20, 21]

$$\mathcal{L}_{gbB'} = \frac{g_s}{2\Lambda} G_{\mu\nu}^a \bar{b} \lambda^a (K_L^b P_L + K_R^b P_R) \sigma^{\mu\nu} B' + h.c., \quad (16)$$

where  $G_{\mu\nu}^a$  is the gluon field strength tensor with the color index  $a = 1, \dots, 8$ , and  $g_s$  is the  $QCD$  coupling constant,  $\lambda^a$  are the fundamental  $SU(3)$  representation matrices. In this Letter, we set the new physics scale  $\Lambda$  to  $M_{B'}$  and assume that the coupling constants  $K_L^b$  and  $K_R^b$  are both of order one in the strongly interacting theory. It should be noted that, using this type couplings, Ref.[22] has considered the contributions of  $B'$  to  $tW$  association production and discussed the possibility of detecting the bottom partner  $B'$  at the  $LHC$ .

From above discussions we can see that the bottom partner  $B'$  can contribute to  $Zb$  production at the  $LHC$  via s-channel and t-channel  $B'$  exchanges, as shown in Fig.3. Our numerical results are given in Fig.4, in which we plot the relative correction parameter  $R_3 = (\sigma^{total} - \sigma^{SM})/\sigma^{SM}$  as a function of the bottom partner  $B'$  mass  $M_{B'}$ ,  $\sigma_{total}$  includes the contributions from the  $SM$  and the bottom partner  $B'$ . Since the contributions of the new couplings  $\delta g_L^b$  and  $\delta g_R^b$  to  $Zb$  production are very small, we have not included their correction effects in the relative correction parameter  $R_3$ . In our numerical calculation, we have considered the constraints of the electroweak precision measurement, such as  $R_b$  and  $A_{FB}^b$ , on the mixing parameters  $S_L$  and  $S_R$ , and assumed the total decay width  $\Gamma_{total}(B') = \Gamma(B' \rightarrow tW) + \Gamma(B' \rightarrow Zb) + \Gamma(B' \rightarrow Hb) + \Gamma(B' \rightarrow gb)$  and  $K_L^b = K_R^b = K^b$ . One can see from Fig.4 that, with reasonable values of the relevant free parameters, the bottom partner  $B'$  can generate significant contributions to  $Zb$  production at the  $LHC$ . For the mixing parameter  $S_R$  consistent with the experimental values of  $A_{FB}^b$  with  $1\sigma$  and  $2\sigma$  error bars,  $0.5 \leq K^b \leq 1.5$  and  $300GeV \leq M_{B'} \leq 1500GeV$ , the values of  $R_3$  are in the ranges of  $1.8 \times 10^{-4} \sim 0.34$  and  $9.7 \times 10^{-5} \sim 0.41$ , respectively. The correction of the bottom partner  $B'$  to  $Zb$  production at the  $LHC$  is comparable to its  $NLO$   $QCD$

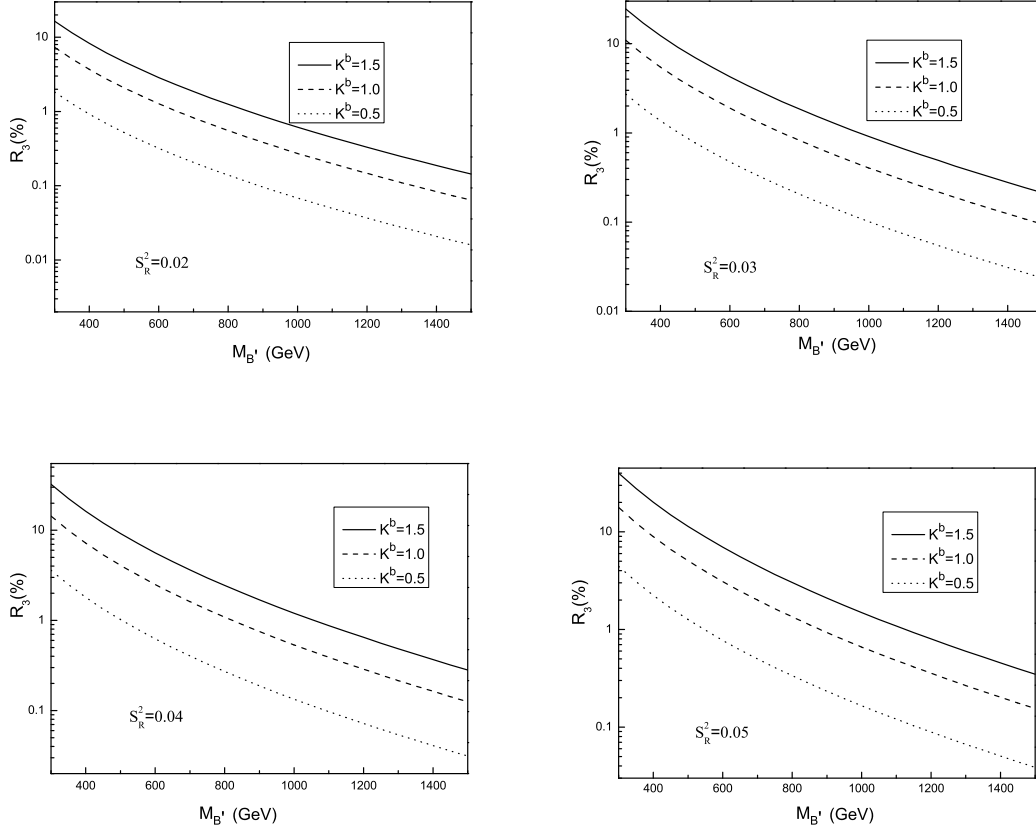


Figure 4: The relative correction parameter  $R_3$  as a function of the bottom partner  $B'$  mass  $M_{B'}$  for different values of the free parameters  $S_R$  and  $K^b$ .

correction and might be larger than the  $NLO$   $QCD$  correction for taking special values of the free parameters.

In the beautiful mirrors model, the correction effects on the  $Z$  polarization asymmetry  $A_Z$  for  $Zb$  production at the  $LHC$  come from two sources: the new  $Zb\bar{b}$  couplings  $\delta g_L^b$  and  $\delta g_R^b$ , and the bottom partner  $B'$ . The contributions of  $B'$  to  $A_Z$  is not related the free parameter  $S_L$  and the contributions of  $\delta g_L^b$  are much smaller than those for  $\delta g_R^b$  and  $B'$ , so we fix the value of the free parameter  $S_L$  to  $S_L^2 = 0.004$ . The relative corrections of the beautiful mirrors model to  $A_Z$  is presented by the parameter  $R_4$ , which is plotted as a function of  $S_R^2$  for  $K^b = 1$  and three values of the  $B'$  mass  $M_{B'}$  in Fig.5. The absolute value of the parameter  $R_4$  increases as  $M_{B'}$  decreases and  $S_R$  increases. For  $300GeV \leq M_{B'} \leq 900GeV$  and  $0.015 \leq S_R^2 \leq 0.05$ , its value is in the range of

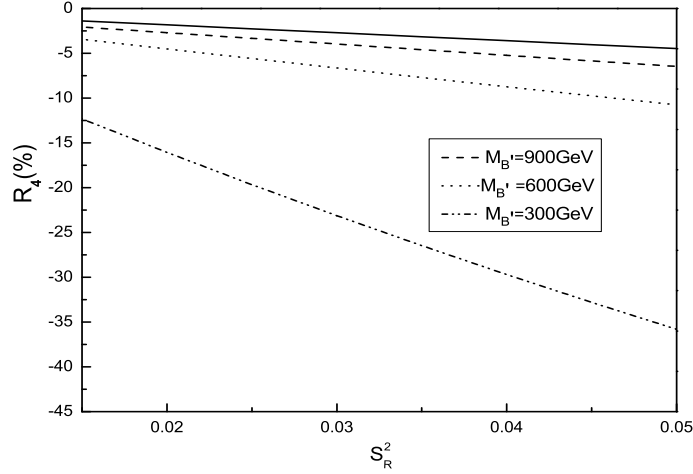


Figure 5: The relative correction parameter  $R_4$  as a function of  $S_R^2$  for  $S_L^2 = 0.004$ ,  $K^b = 1$  and three values of the  $B'$  mass  $M_{B'}$ . The solid line expresses the contributions of the new  $Zb\bar{b}$  couplings  $\delta g_L^b$  and  $\delta g_R^b$  and other lines denote the total contributions of the beautiful mirrors model.

$-35.8\% \sim -1.4\%$ . Thus, the possible signatures of the beautiful mirrors model might be detected at the *LHC* via measuring its correction effects on the  $Z$  polarization asymmetry  $A_Z$  in near future.

#### 4. Conclusions

The electroweak precision measurements can generate severe constraints on the new physics beyond the *SM*. The large deviation between the *SM* prediction and the *LEP* measurement of the  $FB$  asymmetry  $A_{FB}^b$  and the  $Z \rightarrow b\bar{b}$  branching ratio  $R_b$  require that the new physics has large corrections to the *SM*  $Zb_R\bar{b}_R$  coupling  $g_R^{b,SM}$  and small corrections to the *SM*  $Zb_L\bar{b}_L$  coupling  $g_L^{b,SM}$ . In this Letter, we first consider the contributions of the new  $Zb\bar{b}$  couplings  $\delta g_L^b$  and  $\delta g_R^b$  to the hadronic cross section  $\sigma(Zb)$  and the  $Z$  polarization asymmetry  $A_Z$  for  $Zb$  production at the *LHC*. We find that the relative correction of  $\delta g_L^b$  and  $\delta g_R^b$  to  $\sigma(Zb)$  is very small, while can reach 6.8% for  $A_Z$ .

Some new physics models beyond the *SM* predict the existence of the bottom partner

$B'$ . Considering the constraints from the electroweak precision measurements on this new physics model, we further calculate the contributions of  $B'$  to the production cross section  $\sigma(Zb)$  and the  $Z$  polarization asymmetry  $A_Z$ . Our numerical results show that the "beautiful mirrors" scenario can give significant corrections to the physical observables  $\sigma(Zb)$  and  $A_Z$ , which might be detected at the  $LHC$  in near future.

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## References

- [1] G. Aad et al. [ATLAS Collaboration], *Phys. Lett. B* **716** (2012) 1; S. Chatrchyan et al. [CMS Collaboration], *Phys. Lett. B* **716** (2012) 30.
- [2] O. Eberhardt et al., *Phys. Rev. Lett.* **109** (2012) 241802; M. Baak, et al.[Gfitter Group], *Eur. Phys. J. C* **72** (2012) 2205.
- [3] T. Aaltonen et al. [CDF Collaboration], *Phys. Rev. D* **83** (2011) 112003; V. M. Abazov et al. [D0 Collaboration], *Phys. Rev. D* **84** (2011) 112005.
- [4] A. Freitas and Y. -C. Huang, *JHEP* **1208** (2012) 050.
- [5] P. H. Frampton, P. Q. Hung, M. Sher, *Phys. Rep.* **330** (2000) 263.
- [6] CDF Collaboration, *Phys. Rev. Lett.* **106** (2011)141803; CMS Collaboration, *JHEP* **1205** (2012) 123; ATLAS Collaboration, arXiv:1202.6540 [hep-ex]; arXiv:1204.1265 [hep-ex].

- [7] J. M. Campbell, R. K. Ellis, F. Maltoni and S. Willenbrock, *Phys. Rev. D* **69** (2004) 074021.
- [8] M. Beccaria, N. Orlando, G. Panizzo, F.M. Renard and C. Verzegnassi, *Phys. Lett. B* **713** (2012) 457.
- [9] ALEPH and DELPHI and L3 and OPAL and SLD and LEP Electroweak Working Group and SLD Electroweak Group and SLD Heavy Flavour Group Collaborations, *Phys. Rept.* **427** (2006) 257.
- [10] F. Maltoni, G. Ridolfi, M. Ubiali, *JHEP* **1207** (2012) 022.
- [11] Chong-Xing Yue, Yuan-Ben Dai, Hong Li, *Mod. Phys. Lett. A* **17** (2002) 261.
- [12] B. Batell, S. Gori, and L.-T. Wang, e-Print: *arXiv:1209.6382 [hep-ph]*.
- [13] J. Pumplin et al. [CTEQ Collaboration], *JHEP* **0602** (2006) 032.
- [14] G. Aad et al. [ATLAS Collaboration], *Phys. Lett. B* **706** (2012) 295; H. M. Gray [ATLAS Collaboration], *arXiv:1201.4976 [hep-ex]*.
- [15] M. S. Chanowitz, *Phys. Rev. Lett.* **87**(2001) 231802; M. S. Chanowitz, *Phys. Rev. D* **66** (2002) 073002; Xiao-Gang He, G. Valencia, *Phys. Rev. D* **66** (2002) 013004[Erratum-ibid. **D 66** (2002)079901]; *Phys. Rev. D* **68** (2003) 033011; D. E. Morrissey and C. E. M. Wagner, *Phys. Rev. D* **69** (2004) 053001; Junjie Cao, Jin Min Yang, *JHEP* **0812** (2008) 006; C. Bouchart, G. Moreau, *Nucl. Phys. B***810** (2009) 66; Gi-Chol Cho, Y. Kanehata, *Phys. Lett. B***694** (2010) 134; L. Da Rold, *JHEP* **1102** (2011) 034; E. Alvarez, L. Da Rold and A. Szyrkman, *JHEP* **1105** (2011) 070 .
- [16] K. Hagiwara, *Annu. Rev. Nucl. Part. Sci.* **48** (1998) 463; G. Altarelli, F. Caravaglios, G. F. Giudice, P. Gambino and G. Ridolfi, *JHEP* **0106** (2001) 018; D. Chang, W. F. Chang and E. Ma, *Phys. Rev. D* **61** (2000) 037301; F. del Aguila, M. Perez-Victoria and J. Santiago, *JHEP* **0009** (2000) 011; R. A. Diaz, R. Martinez and F. Ochoa,

- Phys. Rev. D* **72** (2005) 035018; A. Djouadi, G. Moreau, F. Richard, *Nucl. Phys. B* **773** (2007) 43; R. Dermisek, S. -G. Kim and A. Raval, *Phys. Rev. D* **84** (2011) 035006; A. Djouadi, G. Moreau and F. Richard, *Phys. Lett. B* **701** (2011) 458; R. Dermisek, S. -G. Kim and A. Raval, *Phys. Rev. D* **85** (2012) 075022.
- [17] D. Choudhury, T. M. P. Tait and C. E. M. Wagner, *Phys. Rev. D* **65** (2002) 053002; K. Kumar, W. Shepherd, T. M. P. Tait, R. Vega-Morales, *JHEP* **1008** (2010) 052.
- [18] D. E. Morrissey and C. E. M. Wagner, *Phys. Rev. D* **69** (2004) 053001.
- [19] N. Cabibbo, L. Maiani, and Y. Srivastava, *Phys. Lett. B* **139** (1984) 459; A. DeRujula, L. Maiani, and R. Petronzio, *Phys. Lett. B* **140** (1984) 253; J. Kuhn and P. Zerwas, *Phys. Lett. B* **147** (1984) 189.
- [20] U. Baur, I. Hinchliffe and D. Zeppenfeld, *Phys. Lett. A* **2** (1987) 1285; U. Baur, M. Spira, P. M. Zerwas, *Phys. Rev. D* **42** (1990) 815; F. Boudjema, A. Djouadi, J. L. Kneur, *Z. Phys. C* **57** (1993) 425.
- [21] Tao Han, Ian Lewis, Zhen Liu, *JHEP* **1012** (2010) 085.
- [22] J. Nutter, R. Schwienhorst, D. G. E. Walker, Jiang-Hao Yu, e-Print: *arXiv:1207.5179 [hep-ph]*.